

INTERNATIONAL ASPECTS OF EARTH RESOURCES
SURVEY SATELLITE PROGRAMS

John Hanessian, Jr.

FACILITY FORM 602

N71-75614

(ACCESSION NUMBER)

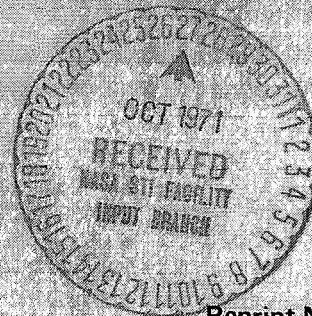
(PAGES) CR-123123

(NASA CR OR TMX OR AD NUMBER)

(THRU) NONE

(CODE)

(CATEGORY)



Reprint No. 8
June 1970

PROGRAM OF POLICY STUDIES IN SCIENCE AND TECHNOLOGY

The George Washington University
Washington, D.C.

Reprinted by permission from the *Journal of the British
Interplanetary Society*, Volume 23, Spring 1970

International Aspects of Earth Resources Survey Satellite Programs

JOHN HANESSION, JR.

*The George Washington University, Washington,
D.C. 20006, USA*

1. INTRODUCTION

1.1 Growth of earth application satellite programs

AS THE WORLD enters its second decade in space, attention is shifting to those programs which have direct application to the needs on earth. Although a lunar landing is acknowledged to be a major engineering feat, the great majority of the nations will take only passing notice.

The scores of developing countries are simply too concerned with their very real and vital problems of preserving their independence and territorial sovereignty, food production, population control, and economic and social development. Manned space flight and exploration by the United States and USSR, regardless of accomplishment, will receive little sustained attention. Likewise the activities in space science, regardless of the interest of individual scientists, research laboratories or academies of science, has little impact on these essential nation-building concerns.

However, the attention of the leaders of these countries has already been captured by the multifaceted applications of earth-orbiting satellites toward very real earth-centred activities. Satellites launched for meteorological purposes (including improved weather forecasting) and for point-to-point communications have received growing attention in recent years. Meteorological data from satellites are currently being routinely supplied to many countries through the international WMO system and many satellite communication links are currently in use. The International Telecommunications Satellite Consortium (INTELSAT), which has over 60 member states, already has several satellites in geosynchronous orbit stationed some 22,000 miles away from the earth. Today, ships navigate with the help of transit satellites and geodesy measurements are underway using the Geos and Pageos satellites. Discussions of the use of satellites for direct broadcast television are currently exciting educators and government officials of many developing countries.

The United Nations Committee on the Peaceful Uses of Outer Space has centered its attention on these matters during the past few years. The UN and its specialized Agencies have exhibited a growing interest in the potential benefits from earth application of earth-orbiting satellites for its less developed member

John Hanessian, Jr.

states and is bringing to bear its institution-wide structure to determine methods for global sharing of the anticipated benefits from such new programs as broadcast satellites and earth resource survey satellites. An extensive literature is developing on these UN-related activities. The focal point within the Secretariat is the Outer Space Affairs Group attached to the Under-Secretary General for Political and Security Council Affairs. It works directly with the General Assembly Committee on the Peaceful Uses of Outer Space and its two sub-committees, one on legal affairs and the second on scientific and technical matters. The first United Nations Conference on the Exploration and Peaceful Uses of Outer Space held in Vienna (August 1968), and the XIXth Conference of the International Astronautical Federation (October 1968) focused considerable discussion on those related subjects.

With this considerable activity already underway, prompt and growing attention has been given during the past few years to the preliminary planning for the launching of satellites for the purpose of conducting global surveys of the earth's resources through the use of remote sensing devices such as multiple cameras capable of continuous photography of the earth's surface. Initial studies have already demonstrated the very great practical benefits to be derived in such fields as agriculture and forestry, geography and cartography, hydrology, oceanography, geology and mineral resources—and these at costs which are minimal compared to manned space activities.

The promise of these benefits, however, will open up certain problem areas that need practical resolution. The successful conduct of the experimental program will be a central concern. Questions regarding the dissemination of such economically valuable data need to be faced. Traditional international legal questions concerning territorial sovereignty may be raised by countries who heretofore have felt impotent concerning the overflight of United States or USSR space vehicles. However, they will have direct interest in the fact that their territory is being photographed and otherwise remotely sensed in such a way as to give other countries potential economic advantages.

1.2 Earth resources survey satellite concept

Every object on the earth's surface absorbs, reflects and emits electromagnetic energy at unique wavelengths, most of which are not in the visible range of the spectrum. These spectral characteristics, when collected, compared, and analyzed, make it possible to distinguish objects and obtain economically useful information relating to their physical characteristics.

Remote sensing (acquisition of information about objects or phenomena not in contact with the data-gathering device) is one (relatively new) technique which can be utilized to obtain high resolution images of these spectral characteristics. These images can then be processed and analyzed by skilled interpreters. Although either aircraft or earth-orbiting satellites (or a combination of the two) can be utilized to house such remote sensors, satellites have a basic advantage in that they have the ability of providing repetitive synoptic coverage.

International Aspects of Earth Resources Survey Satellite Programs

A number of studies have suggested a wide range of potential applications of earth resources data obtained from space. Enough is already known, based on experiments performed by aircraft and from photographs obtained during the Gemini and Apollo manned space flights, to justify considerable confidence in the utility of resource data acquired from space. However, there is no accurate method of determining which applications are feasible and to what extent until an experimental ERS program actually obtains space derived data considered potentially useful. The summer studies in 1967 and 1968 conducted at Woods Hole, Massachusetts, by the United States National Academy of Sciences, at the request of the National Aeronautics and Space Administration, concluded that 'potential economic benefits to our society from space systems are enormous.' This optimism has also manifested itself in statements made by the United States House of Representatives Subcommittee on Space Science and Applications, which has suggested that 'an earth resource satellite system unquestionably presents NASA with an excellent opportunity . . . to achieve tangible economic returns.' The subcommittee has also claimed that 'the unique observation and data collection capabilities of the earth-orbiting satellites are such that it promises to become an instrument having a profound impact upon the discovery, management, utilization, and conservation of the world's natural resources within the next few years.' Both Houses of Congress have become increasingly interested in earth-oriented space applications. They are much less costly than manned exploration projects and potential benefits are far more realistically explained to the public. The annual NASA authorization Hearings include lively discussions of these questions.

1.3 Initiation of the ERTS program

As the first step in the orbital testing of the remote sensing concept, NASA has developed the Earth Resources Technology Satellite (ERTS) program. Activity in the earth resources area within NASA dates back to at least 1964 when the Manned Spacecraft Center (MSC) at Houston commenced a program of aircraft flights to define possible sensor systems for remote sensing use. Mission plans for the aircraft program have been developed through coordination between MSC, the United States Geological Survey (USGS) of the Department of the Interior, the Department of Agriculture, and the Naval Oceanographic Office.

Studies conducted during 1964-1966 gradually led to the conclusion that a light-weight automated ERS satellite appeared feasible, and that a program aimed at developing an experimental unmanned satellite should be initiated. During 1967 the Goddard Space Flight Centre carried out a six-month feasibility study of an unmanned ERTS program. Subsequently project definition studies were conducted, and in late 1969 the final systems design will be selected, and a contract let for systems development and satellite fabrication. The first launch in the ERTS program is estimated for early 1972.

The ERTS-A satellite will carry two types of imaging sensors: three return-beam vidicon cameras will provide images with approximately 300-foot ground resolution in three spectral bands in the visible and near-infrared portions

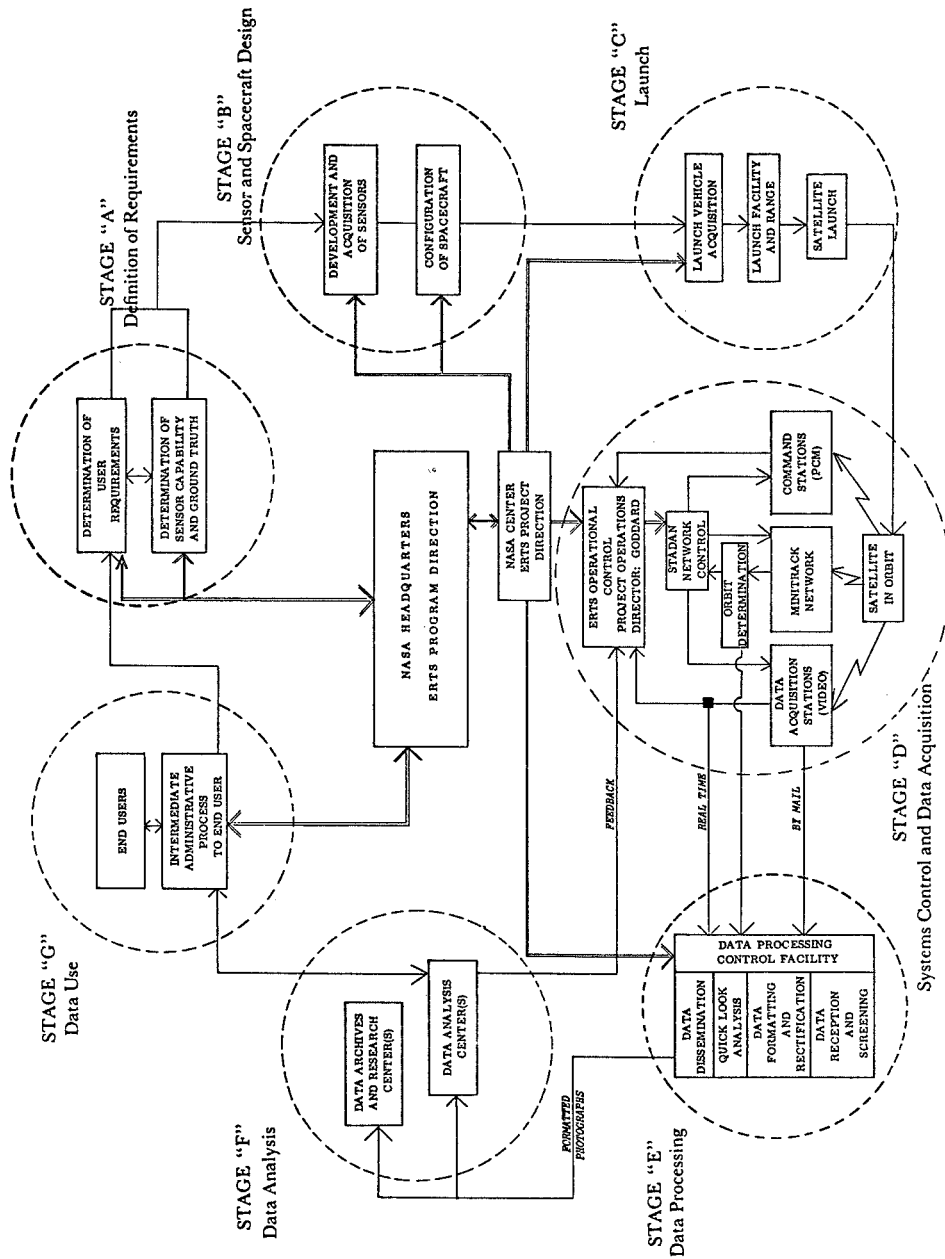


Figure 1. ERTS experimental program: functional system model developed by The George Washington University Program of Policy Studies in Science and Technology.

International Aspects of Earth Resources Survey Satellite Programs

of the spectrum, and a 4-channel multispectral scanner which will provide point images. It is also intended that ERTS-A will carry a data collection system to relay data from remotely-located ground sensors to data acquisition stations. An ERTS-B satellite will be launched approximately one year after ERTS-A.

2. EARTH RESOURCE SURVEY SATELLITE PROGRAMS: OVERALL SYSTEM DESCRIPTION

2.1 Introduction

The technical framework of an ERS system, combined with its potential global scope, raises complex problems in system development, organization, and management. Examination of these problems out of their specific technological context would result in inadequate or superficial consideration of policy alternatives related to broadening international participation in the ERTS program. Accordingly the following discussion describes the technical features of the initial ERTS program in sufficient detail to highlight effectively certain policy problems linked to the aspects of the system.

The primary thesis of this study is that the task of developing and operating an ERTS system, although in some respects similar to problem areas which have been faced in part in earlier projects of a similar complex nature, does present certain unique aspects. The technological capability required to develop the sensing devices used in the system, to combine them into a satellite package, to launch that satellite, to track it and acquire data from it, to process and analyze that data, and finally to disseminate it efficiently to users, is formidable. Realistically, such total capability is possessed only by the most advanced industrial states.

However, the potential benefits of an ERTS system seem great, not only for developed countries, but also for states which are still at early stages in the process of modernization, states which are unlikely to have the degree of technological skills required for successful utilization of an ERTS system and its outputs. How to make these benefits available to those states who desire to use them, regardless of their level of technological development, presents a problem, and an opportunity, for the international community.

Figure 1 has been prepared to depict the several stages of the experimental ERTS program. This diagram has been developed in coordination with the ERTS project directors both at NASA Headquarters and the Goddard Space Flight Center. Although specific details of the system shown in Fig. 1 may change as the ERTS program develops, it is likely that the functional categories and relationships depicted in this diagram will remain relatively fixed. The diagram divides various steps involved in developing and operating the Earth Resources Technology Satellite into 'stages'. These stages are:

- (a) Definition of requirements and potential users
- (b) Sensor and spacecraft design
- (c) Launch of satellite

John Hanessian, Jr.

- (d) System control and data acquisition
- (e) Data processing
- (f) Data analysis
- (g) Data use.

Although these stages are separated on Fig. 1 for analytic purposes, they are not necessarily listed in time sequence. The ERTS program will be an ongoing experiment, and there will be a constant process of feedback within the system resulting in shifting requirements, design parameters, operational techniques, data processing and data analysis procedures, and data uses over time.

2.2 Definition of requirements and potential users

Several years of intensive study by the full range of those interested in applying techniques of remote sensing from space to earth resource surveying have resulted in the identification of some unique spectral signatures, development of a number of remote sensing techniques, and the selection of a number of feasible applications for an ERS program. Included in these studies has been a NASA experimental program using aircraft-mounted remote sensors, and basic studies conducted by a number of government agencies, university and other non-profit research centers, and potential industrial contractors.

From these studies of feasible earth resource survey applications, NASA which has the responsibility for the research and development leading to an experimental earth resource satellite system and other government agencies which are potential users of ERS data have chosen those applications for which remote sensing from space, even during the research and development phase of the program, may offer significant actual benefits.* These applications are:

Agriculture

- (a) identification and measurement of species to determine land use
- (b) measurement of growth rate
- (c) Identification of factors influencing crop and forest stress
- (d) prediction of yield based on assessments of crop vigor and health.

Geography, Geology, Hydrology

- (a) Classification of areas by geological or geomorphological characteristics such as surface composition, water runoff patterns, etc.

* These and related topics have been comprehensively explored and integrated in the series of reports resulting from the Summer Study of Space Application conducted for NASA by the National Academy of Sciences-National Research Council at Woods Hole, Massachusetts, during the summers of 1967 and 1968. These reports have been published as a series by the National Academy of Sciences, Washington, D.C. under the general title *Useful Applications of Earth-Oriented Satellites*. Reports in the series which contain information pertaining to earth resource surveys are: *Report of: Central Review Committee; Panel 1: Forestry-Agriculture-Geography; Panel 2: Geology; Panel 3: Hydrology; Panel 5: Oceanography; Panel 6: Sensors and Data Systems; Panel 8: Systems for Remote-Sensing Information and Distribution; Panel 12: Economic Analysis; Panel 13: Geodesy and Cartography.*

International Aspects of Earth Resources Survey Satellite Programs

- (b) monitoring of time variant phenomena such as population movements, transportation patterns, and environmental hazards to man
- (c) measurement of hydrological parameters such as soil moisture, snow depth, stream flow, etc.

Oceanography and Hydrography

- (a) measurement of sea state
- (b) location and tracking of major ocean currents
- (c) mapping of sea ice
- (d) detection of specific phenomena of limited area and varying locations such as fish schools, oil slicks, Red Tide, etc.
- (e) analysis of the shoreline.

Even this selected list of applications imposes varying and to some extent conflicting requirements on sensors, spacecraft design, and other technological aspects of a research and development program, the primary aim of which is demonstrating the feasibility of the ERS concept. Thus, a set of mission goals have been determined which represent an optimal compromise between the above set of applications and the technical requirements of designing an ERTS for a 1972 launch. This compromise has been based on the following criteria:

- (1) availability of sensor technology;
- (2) priorities assigned to possible applications;
- (3) commonality of a given sensor system to several of the selected applications;
- (4) developments inherent in other NASA applications missions such as the ITOS and NIMBUS satellite series.

On the basis of these criteria, the primary goal of the initial ERTS missions has been established as the development of the capability of acquiring high-spatial resolution multispectral images of the earth's surface. Technology for obtaining such images, both in the visible and near-infrared range, is now under development.

In addition to defining requirements for the space segment of the system, coordinated planning during stage A has aimed at establishing requirements for the ground segment of the system, especially with respect to operational control and data processing. This planning has been based on the concept of a co-located operational control center and national data processing facility.

2.3 Sensor and spacecraft design

Once the interaction between desirable applications and available technology has resulted in specification of primary mission goals for the initial ERTS launches, the design of a total system to accomplish those goals can proceed. Because the ERTS program is primarily an experimental one, aimed at providing perfor-

John Hanessian, Jr.

mance evaluations of earth resources sensors and other basic design data useful for making an overall estimate of the feasibility and capabilities of an earth resource survey satellite program, a conservative design philosophy is being followed for the first ERTS system. The design aim is to modify an existing spacecraft chassis to accommodate the selected sensors, the data collection system, and the accompanying data storage and transmission systems. Such spacecraft chassis include those currently used in the NIMBUS, TIROS, and Orbiting Geophysical Observatory programs or some modification of an Agena stage.

The payload for the initial ERTS will include a high spatial resolution television camera system, consisting of three cameras each of which will obtain images in a different portion of the spectral band. The blue-green band (0.475 to 0.575 microns) provides maximum water penetration; the visible red spectrum (0.580 to 0.680 microns) is useful for observation of land forms. The near-infrared band (0.690 to 0.830 microns) assists in locating water bodies and provides information on plant vigor. The three return beam vidicon (RBV) television cameras will be programmed to record simultaneous images every 25 seconds. At the 492 nautical mile height of the planned orbit, such images will cover an area approximately one-hundred miles on each side. The 4500-line vidicon image which the RBV is expected to provide with optimum conditions will produce approximately a 300-foot ground resolution. There will be 11 grey lines of tone discrimination in the image, i.e., an image superior to home television by about a factor of ten.

Also included as part of the sensor payload on ERTS will be a four-channel multispectral point scanner. This sensor will effectively complement the television camera system since it will obtain scan line images simultaneously in each of four wavelength bands, three of which will duplicate the bands sensed by the TV cameras.

A data collection system (DCS) is the third element in the payload for the initial ERTS. This is a communications system capable of interrogating various ground-based remotely located sensing devices such as stream flow gauges, snow depth gauges, or heat-measuring devices. A valuable feature of the use of the DCS is its ability to collect such ground-based measurements in a given region at the same time as images of the region are obtained by the orbiting ERTS. The data from these ground-based sensing devices will be collected on the spacecraft and, will be either transmitted directly to the earth terminals in real-time or stored onboard for later transmission. Data collection and relay devices of this type have already been tested by NASA on other experimental satellites.

ERTS will carry two wideband video tape recorders, currently under development. These recorders will be able to store the television system and/or scanner output, and to replay them on command from the ground. In this way, images obtained of areas not within range of a data acquisition station can subsequently be retrieved. The satellite will also have a narrow-band tape recorder to store data collected by the data collection system and other pulse code modulated (PCM) data.

International Aspects of Earth Resources Survey Satellite Programs

2.4 Launch of satellite

The initial launch in the ERTS program is scheduled for the first quarter of 1972. It is currently planned to use a Delta N launch vehicle, capable of placing 1200-1600 pounds in the desired orbit. This is a standard launch vehicle, highly reliable, which is manufactured by the McDonnell-Douglas Corporation. The launch site will be the Western Test Range at Vandenberg Air Force Base, California. This launch site is normally used for United States launches into near-polar or polar orbits, since the launch path for these orbits from the Western Test Range extends over the Pacific Ocean. By contrast, a launch into polar orbit from Cape Kennedy would involve booster operation over populated areas in the Caribbean.

The orbital height, angle of inclination, and time of launch of the ERTS will be planned to provide the following characteristics:

- (1) the orbit will be sun-synchronous, thereby providing repetitive observations of specific locations at the same local time;
- (2) the local time at which images are recorded will be such that the sun will be 25° - 30° above the horizon (at 50° North latitude and vernal equinox);
- (3) the orbit will be circular at a 99° inclination to the equator and 492 nautical mile height, providing global coverage every 18 days, image overlap in the direction of flight, ten per cent image sidelap from the adjacent orbit, and an operating life greater than one year.

2.5 Systems control and data acquisition

This stage of the ERTS program encompasses tracking the satellite and determining its orbital parameters, exercising operational control over the satellite, acquiring data from it, and transmitting that data to the data processing center. Overseeing these functions will be an Operations Control Center (OCC) located at the Goddard Space Flight Center in Greenbelt, Maryland. Existing NASA tracking, orbital determination, data acquisition, and communications systems will provide support for ERTS operations.

The minitrack system, which is an integral part of the NASA Space Tracking and Data Acquisition Network (STADAN), will be used to track the ERTS. Tracking information will be communicated to the orbital determination center at Goddard, which will then provide the ephemeris information needed both by the OCC and by the data processing center.

The OCC will use this orbital information, together with other data, to prepare a spacecraft activity plan, which will then be coordinated with the data acquisition network. The OCC will generate the commands for the control of ERTS and will also monitor telemetry data from the satellite to evaluate spacecraft and sensor performance. To perform their functions, the OCC will utilize a computer system and appropriate displays of associated software.

Current plans call for the utilization of three data acquisition stations to

John Hanessian, Jr.

receive the wideband video output from ERTS-A. These stations are located at Fairbanks, Alaska; Corpus Christie, Texas; and Greenbelt, Maryland. These stations provide the capability of real-time coverage of the United States including Alaska, and Canada. If desired other STADAN stations could be modified to provide the capability for near-global coverage in real-time. These stations are located at Barstow, California; Rosman, North Carolina; Canberra, Australia; Santiago, Chile; Quito, Ecuador; Tananarive, Malagasy Republic; and Johannesburg, South Africa.

Even though current plans for the use of three data acquisition stations located in the United States will limit the real-time coverage of ERTS to North America, images of other areas of the earth can be obtained, stored in the on-board tape recorders, and played back during night-time passes over the United States stations. In this way, at least occasional coverage on a near-global basis will be possible. Repetitive near-global coverage would require a decision to modify additional data acquisition stations to receive the wideband video output of ERTS. A minimum 40-foot dish antenna is required before such modification is possible.

The ERTS data output, both video and PCM, will be recorded on magnetic tape at the data acquisition station. (PCM data can be acquired at any STADAN station). The tape containing the video data will be mailed to the data processing center. The PCM data will be transmitted over the NASA communications network to the OCC and the data processing center.

It is possible to calculate some approximate estimates of the volume of video data to be produced by ERTS. The following computations, which are based on maximum output from the television system, are illustrative. Each triplet (an image in each spectral band) requires 25 seconds to record; a maximum of 30 minutes of imaging time per orbit seems likely, since on an average only one third of the orbital period will be over land. This would produce 72 triplets per orbit. There will be fifteen orbits per day; thus there could be 1080 triplets, or 3240 images, produced daily. Of course, factors such as cloud cover, time constraints on passes over data acquisition stations, and other factors will reduce the volume of data output.

2.6 Data processing

The NASA Data Processing Facility (NDPF) for ERTS will be located at the same site as the Operations Control Center so that there can be close interaction between them. The NDPF will perform two basic functions:

- (i) Transform the data output of ERTS into various user-oriented formats;
- (ii) store all data temporarily in retrievable and reproducible form.

The NDPF will routinely produce annotated and registered hard film copies of television and scanner images. The NDPF will also produce computer listings or digital tapes containing data collected by the data collection system and other information needed to analyze that data. The portion of the NDPF which will

International Aspects of Earth Resources Survey Satellite Programs

process incoming raw data will be known as Telemetry and Image Data Processing (TIDP).

In addition to this routine processing, it is envisioned that approximately 10 per cent of ERTS data will be given special treatment by TIDP upon user request. This special processing may include digitization of precision gridding, registration, and scaling onto a standard map projection.

A Data Services Laboratory (DSL) will also be a major element in the data processing center. It will control the scheduling of data processing, perform data accounting and serve as the interface between the NDPF and ERTS data users.

Data from the television system will be processed to produce 9" x 9" photographs, commensurate with a 1:1,000,000 map scale. These photographs will be annotated with the following information: time and date taken, orbit number, spacecraft position, sun angle, location of center of picture, heading, spectral band, and acquisition station. Data from the multi-spectral scanner will be processed to produce similarly-annotated 9" film strips.

Each black and white image will be processed to produce a master copy per spectral band and several negatives, positive transparencies, and positive print. Cloud-free images will also be processed to produce color composite photographs.

The DSL will produce two 'montage catalogs' for each 18 day cycle in which the satellite covers all areas of the globe. One catalog will display all television images collected during that cycle; the other, all scanner images. These catalogs will allow users to obtain an overall impression of image quality, quantity and information content. Using the montage catalog, data users will be able to identify and order individual images, or to request special processing services. In order to produce this processed data, the DPC will utilize high resolution film recorders, digital computers, and complete photographic processing facilities.

2.7 Data analysis

The procedures likely to be used in the analysis of processed ERTS data will include both simple and complex techniques. The complexity of the data analysis procedures will vary according to the application to which information extracted from the data is directed. For many geological applications, for example, visual analysis of television images using conventional photoanalytic techniques will provide the required information. For agricultural applications such as crop yield predictions, computer analysis of digitized scanner data will be needed.

Similarly, data analysis can be performed on a centralized or decentralized basis. For some applications, especially those involving the amassing of information on a continental or global basis, central data analysis facilities will be needed. For other applications involving the integration of information obtained from ERTS data with other information gathered locally, analysis will also be performed locally.

John Hanessian, Jr.

Because many copies of a given television or scanner image can be generated from each master, providing the processed data to various data analysis centers will not be difficult. A more serious limitation is the relative scarcity of skilled photointerpreters able to utilize the ERTS data. The usual practice in applying photointerpretive techniques to the analysis of data similar to that which will result from ERTS is to train disciplinary specialists in such techniques so that they can efficiently extract the appropriate information from the data. Since in many countries the availability of such specialists is already limited, this may present an important consideration regarding their potential participation in ERTS.

The equipment required for data analysis will also vary according to the complexity of the analysis. For visual interpretation, relatively inexpensive tools such as mechanical scanners, image enhancement devices, and stereo viewers are used. For the type of computer analysis of digitized data contemplated, a large and expensive computer system such as the IBM 360 would be required.

2.8 Data use

ERTS data will have a wide variety of applications and a comparably wide variety of users. The United States Department of Agriculture, for example, believes that agricultural information derived from ERTS data will be useful to (i) a number of agencies within the Department such as the Agricultural Research Service, the Economic Research Service, the Forest Service, and the Soil Conservation Service, and (ii) to other organizations such as regional interstate governmental agencies, state agencies, land-grant universities, and private organizations such as utilities, agricultural suppliers, land developers, forestry, farming, and ranching [1].

The US Geological Survey has made a similar estimate of the users of ERTS data which includes (i) a number of organizations within the Department of Interior such as the Geological Survey, the Bureau of Reclamation, Federal Water Pollution Administration, the Office of Mineral Exploration, National Park Service, the Bureau of Land Management, and the Bureau of Mines, and (ii) other organizations such as local water districts, the petroleum industry, private mining interests, geographers, the grazing industry, and commercial fisheries.

Each of these agencies as well as other government organizations planning to use earth resource survey information expects to use existing channels for disseminating information to users. They also have existing policies regarding the timing of information releases to avoid preferential treatment. These policies will be applied to the ERTS dissemination process.

3. TECHNICAL CONSTRAINTS OF THE SYSTEM ON POTENTIAL INTERNATIONAL PARTICIPATION

Perhaps the most basic technical limitation on opening the initial program to international participation is its *experimental* nature. As it is the first (open) attempt to use an unmanned satellite specifically for obtaining high-resolution

International Aspects of Earth Resources Survey Satellite Programs

images of the earth using advanced sensor systems, the program is intended primarily to determine what can be gained by such an undertaking. Before the first ERTS is launched, the exact quality and utility of the images it will return will be unknown. In a parallel fashion, research on 'ground truth'—signature identification and interpretation of images of the quality expected to be produced by ERTS—is far from complete, and whether the images obtained from orbit can be combined with 'ground truth' information to yield valuable analyses will not be demonstrated until both the satellite derived images and better ground truth data are available. Thus any nation which is interested in participating in the early stages of the ERTS program, will be faced with a decision of whether to allocate resources to an undertaking with uncertain results.

Even if the images produced by early ERTS launches are of relatively high quality, it is not currently a requirement within the planned experimental program to provide much coverage of the earth's land masses outside of North America. Thus, NASA would not be able to provide images on a regular, repetitive basis to nations outside of North America. This limitation results not from anything inherent in the design of the satellite itself, but rather from the current plans to utilize three existing data acquisition stations to receive video data from the satellite. (See discussion in Section 2.5 above for explanatory details.) The use of these three data acquisition stations will limit the amount of data that can be obtained from the satellite on each orbit to that which can be transmitted in real time or 'dumped' from the on-board video tape recorder during passes over these stations; the combined time over all stations will be of the order of 20 minutes or less per orbit.

Since the highest priority in the initial experimental program will be given to obtaining repetitive coverage of the United States, most of this time will be spent transmitting images of North America. This constraint could, however, be eased, even without additional data acquisition stations, by using night-time passes over United States stations to 'dump' images obtained from portions of the earth where it is day.

Another potential limitation on the feasibility of other nations participating in ERTS is the limited supply of trained photointerpreters who are able to analyze the images obtained from the satellite and extract from them the types of data that have the desired economic or social value. Most of the available photointerpreters within the United States are employed by the planned user agencies of ERTS data (e.g., US Geological Survey, US Department of Agriculture) and there is no ongoing program connected with the ERTS project to train additional personnel.

This suggests that, if other nations do decide to participate in the ERTS program, they must for the most part expect to provide their own photointerpretive personnel. This requirement is typical of the kind of decisions regarding financial, technical, and human investments that a nation considering participation in the program will have to make. These decisions must be made in the face of the above-mentioned uncertainty with respect to the short-term, and

John Hanessian, Jr.

perhaps even long-term benefits of an investment in an earth resources program in relation to other uses of a nation's scarce resources. Depending on the form of participation a nation might contemplate, the costs could run from tens of thousands of dollars for training a few photointerpreters and providing them with necessary equipment to an initial investment of \$5-\$10 million if a nation wishes to establish its own data acquisition and processing facilities.

Each nation participating in the ERTS program would also have to develop some sort of management structure to implement the program within its own borders. Providing such technical and administrative assistance will probably need to be an integral part of any arrangements that are made for international participation in the ERTS program. This assistance could be provided by (i) United States agencies, such as the Agency for International Development (AID); (ii) regional organizations such as the Inter-American Development Bank; or (iii) global international agencies such as the World Bank or such other United Nations organizations as UNITAR, UNDP, UNESCO, FAO or ECOSOC.

Some mention should be made of the experience to date in implementing the cooperative program between NASA and Brazil (the similar NASA-Mexico program began during the spring of 1969). One intended purpose of this program has been to familiarize Brazilian personnel with the acquisition, processing, reduction, and analysis of remotely sensed data (in this case obtained from aircraft). In order to accomplish this aim, Brazilian personnel have visited the Manned Spacecraft Center in Houston and potential United States user agencies. This cooperative program and the resultant experience gained from it can be used as a model by those countries which might anticipate preparations for participation in the ERTS program.

4. UNITED STATES FOREIGN POLICY CONSIDERATIONS REGARDING INTERNATIONAL PARTICIPATION IN ERTS

4.1 Opportunities, objectives and goals

The existing desire in the international community for some form of participation in the ERTS program presents an intriguing opportunity for the United States to take advantage of this space application program as a means of contributing to several relevant US foreign policy goals. Among such goals which may be listed are the following:

- (1) The development of better relations with other countries by helping them apply new space technology to their national problems;
- (2) The strengthening of the United Nations, its Specialized Agencies, and other international organizations by involving them in the development and application of a new space derived technology which promises broad, economic and social benefits on a global scale;
- (3) The minimization of the potential international administrative, legal, regulatory, economic, and political difficulties arising from a subsequent operational ERS system by early involvement of individual nations and international organizations in the development stage of

International Aspects of Earth Resources Survey Satellite Programs

the program in such a way as to smooth the transition from the experimental to the operational stages; and

- (4) The removal of a potentially contentious issue from world politics (the possible claim by some countries that earthward-looking satellites equipped with remote sensors could be used for economic and/or military intelligence purposes) by opening up the program to international participation.

These goals are consistent with the 1967 Treaty of Principles Governing the Activities of States in the Exploration and Use of Outer Space. Some relevant provisions of this Treaty are:

Article I: Forcefully states that such activities 'shall be carried out for the benefit and in the interest of all countries irrespective of their degree of economic or scientific development.'

Article III: Provides that the signatory states shall carry out such activities 'in accordance with international law,' and,

Article VI: States that such countries will 'bear international responsibility for national activities in outer space . . .'

In any discussion of the foreign policy aspects of earth observation satellites some mention must also be made of the relationship of such programs to policy goals regarding arms control initiatives. A revival of the earlier 'open skies' proposal, but, this time for the 'economic benefit of all mankind' (rather than for military purposes), would bring a considerable degree of international confidence in a satellite inspection system. The gradual acceptance by the community of nations of, and participation in, an earth observation program like ERTS, would do much to help ameliorate the adverse reaction that has, in the past, met suggestions concerning the establishment of arms control programs which include surveillance techniques. It could also be viewed, if desired, as a step toward future acceptance of internationally institutionalized programs of space surveillance [2].

4.2 Potential policy problems

It has been suggested that the ERS program, if not placed in an international context, will be open to criticism and possible fears that the program might be used as a vehicle for obtaining intelligence data having strategic or economic exploitive significance. The so-called 'eye-in-the-sky' problem, if justified, would certainly present major international political and legal problems.

Critics have suggested that countries, which heretofore have not complained (in terms of jurisdictional sovereignty) about overflying orbiting earthward-looking satellites, will have a greatly increased concern in this particular program. The primary reason given for the absence of jurisdictional complaints to date is that, in the past, earth application satellite programs have been (i) purely scientific in nature, (ii) integrated into an international system (meteorological and communications satellites); or (iii) completely secret military pro-

John Hanessian, Jr.

grams conducted without publicity by the United States and the USSR. The ERS program, on the contrary, will be, by its very nature, an open program aimed at obtaining economically valuable information. This objective, it is stated, implicitly opens up the program to charges of possible misuse for exploitive purposes. Despite the expected ground resolution of 300 ft (or even greater), it has been suggested by some that the extracted data could be used by some countries to obtain information of strategic value.

In addition, it is quite possible that any technologically advanced country, by having access to ERS data, could conceivably utilize such data for the economic exploitation of a lesser developed country. Such exploitation could include the obtaining of advantages in mineral prospecting, or fishing; or the utilization of crop information as a basis for planning marketing strategies. Developing countries may also be concerned that industrialized countries with their extremely advanced technological ability combined with readily available sources of capital financing, could use the data to exploit economic resources in their own countries.

However, it is submitted that, at least during the experimental period, the nature of the problem is more political and psychological than actual and technical. Several relevant technical aspects of the ERTS program which will inhibit the use of the data for intelligence purposes must be taken into consideration: (i) data from the initial program will have a ground resolution of approximately 300 feet, (ii) it is expected that, on the average, some 75 per cent of the photographic coverage on each orbit will be of limited value due to complete or partial cloud cover, and (iii) the planned 492 nautical mile altitude polar orbit will allow repetitive coverage of a given area only once every 18 days—thus providing only a limited opportunity for investigation of time-variant phenomena.

In addition, it should be borne in mind that neither the United States nor the USSR would need to utilize ERTS data to obtain information of strategic value. Both countries already operate, for intelligence purposes, reconnaissance satellites which provide for considerably greater ground resolution. (Published estimates have indicated figures as low as a few feet.)

4.3 Need to help prepare developing countries for participation in ERTS

As has been discussed earlier, developing countries have already begun to evidence an interest in the potential benefits to be derived from participation in earth resource survey satellite programs. In broadening the ERTS program to include the participation of developing countries, a number of preliminary investigations and inventories need to be completed by these countries, if such participation is to be productive. These should include:

- (1) The determination of the most appropriate user requirements within the country.
- (2) The preparation of a national inventory of the possible availability of necessary technical personnel such as photointerpreters, data processors, and

International Aspects of Earth Resources Survey Satellite Programs

computer technicians as well as scientific and technical personnel such as agronomists, geologists, and hydrologists, who are needed to properly utilize the remotely sensed data which will be made available.

(3) The completion of a preliminary feasibility study during which all essential factors are carefully analyzed: user requirements; availability of necessary personnel, equipment, communications, and management; cost; probable benefits, etc. A rough costs/benefits analysis (in terms of both short-term aspects and long-term potential) would be necessary to enable the government in question to make its decision regarding possible level and scope of participation. Such a study would need to be carried out on a systematic, society-wide basis in order to identify (and perhaps suggest remedies for) potential conflicts of interest, potential duplication of efforts, levels of expected secondary and tertiary needs which will be generated by the program, and also alternative means of accomplishing the same tasks.

(4) Once such a feasibility study is completed, the government would need to carry out a coordinated governmental (with private interests as necessary) planning exercise to establish an operational plan for the country's participation. Necessary coordinative and institutional adjustments would need to be spelled out. Plans for financing, preparation of trained personnel and the other relevant requirements would need to be prepared.

To help developing countries in carrying out such preliminary studies presents a challenge for both the United States and the world community. As a beginning, it will be necessary for the provision of sufficient technical information concerning the nature of the expected program and the data it will produce—so that these studies can be realistically carried out. In addition, the United States, through its appropriate agencies, such as A.I.D., could play an active role in assisting these countries in the conduct of these studies.

However, in considering how to relate technical assistance programs to these ERS study needs, one must take into consideration that developing countries often prefer to have such assistance channeled through multilateral organizations. The UN, ECOSOC and FAO are already investigating their future role in helping developing countries benefit from earth resource survey programs.

5. POSSIBLE FORMS OF INTERNATIONAL PARTICIPATION IN ERTS

5.1 Introduction

A most important first step is to examine possible mechanisms for international participation in the ERTS program which are feasible within the technical constraints discussed above. This examination must attempt to integrate the factors supporting the idea that international involvement is desirable with the relevant factors acting as technical and administrative constraints on the scope and form of such involvement. In this way a realistic and balanced plan for

John Hanessian, Jr.

international participation can be developed—one designed so that promise does not exceed fulfillment. Thus, the technical constraints of the planned system must act as boundary conditions for the examination.

5.2 International participation in ERTS

Taking these factors into consideration, several mechanisms for international participation in ERTS can be considered. Listed in terms of increasing complexity, they are:

5.2.1 Provision of completed analyses of the ERTS-derived photographic images to participating countries

In this form of participation the United States would perform photointerpretive analyses of selected ERTS data for users in other countries, i.e., process and analyze the photographic images taken of their territory by remote sensors aboard ERTS. This procedure may require, for some applications, that 'ground truth' information be provided by the participating countries. The United States would provide these analyses based on ERTS data to the participating countries without cost, or charge the marginal fee to cover the added processing and interpretation costs.

This appears to be the simplest form of possible participation in the ERTS program especially for less-developed countries, who perhaps have the most to gain from such participation but the least current capability to undertake it. It requires the least expense for these countries and also the fewest trained personnel to use the information obtained. The organizational arrangements in the recipient country to distribute and use the ERTS derived information would be as simple as is necessary for any expected form of participation.

Other advantages are that the necessary bilateral arrangements for providing such analyses would be a natural outflow of previous and current United States international cooperative agreements, and that this form of participation could provide an opportunity for a large number of countries to become involved—an arrangement which would help ameliorate possible fears of exploitation.

However, this form of participation, would do little to aid countries in developing their own capabilities in photointerpretation, data processing and associated technological activities. The transfer of information would not be paralleled by a similar transfer of technological skills. Another major problem is that the addition of such a requirement would probably overtax the photointerpretive capability of the United States unless a program was initiated to train additional personnel.

Finally, it is likely that some technical assistance would need to be provided to participating nations so that they could make effective use of the information provided them. This assistance need not be an extensive or a costly undertaking, presuming that what would be necessary would be to assist trained agronomists, geologists, etc., to learn how information from ERTS images can be used to aid them in their countries.

5.2.2 Provision of unanalyzed processed photographic images to participating countries for interpretation by them

Unanalyzed negatives or photographic prints would be provided to participating nations which could then utilize them according to their user requirements. Unless the currently planned number of data acquisition stations were increased this procedure would still provide only occasional coverage of areas outside the United States. The material would be forwarded to individual nations which requested it or to a group of nations joined together on a regional basis for the purpose of utilizing earth resources survey information in their common interest. The United States would maintain the responsibility for processing the raw video output of ERTS into negatives and finished photographs and of adding the information to the images (coordinates, data and time of acquisition, etc.) needed so that they can be analyzed.

The participating nations (or regions) would require both the facilities and the personnel needed to perform analytic (and perhaps processing) tasks. They could obtain these capabilities through technical assistance provided by (i) the United States or another industrialized country, (ii) an international or regional organization, or (iii) private industry under contract.

This form of participation would, therefore, require the investment of a significant amount of resources by the participating country, including the training of data analysts, and the purchase of the necessary equipment.

The advantage of this mechanism is that it would allow the participation of other countries, but would not interfere with the primary purposes or the operation of the program. For these reasons, and in keeping with the open nature of the program, NASA is planning on utilizing this mechanism during the experimental ERTS program.

This form of participation would result in the development of significant skills in data analysis in these countries, thereby increasing their technical capabilities. Since the costs of this alternative would still be relatively low, participation would be attractive to a number of nations, though fewer than in the previous approach. The advantages of pooling resources on a regional basis for data analysis may be of particular interest. This form of participation is likely to be more meaningful to most nations, since it does involve them in the ongoing process of learning how to use ERS information.

The disadvantages of this mechanism are the inverse of many of its advantages. The major need of a participating country will be personnel able to interpret ERTS—gathered data. These personnel would include individuals whose backgrounds are in one of the disciplines to which remote sensing information is applicable and who have been trained in the interpretation of that information. These, then, will be highly skilled individuals, and many countries do not have such individuals in large numbers. Whether a developing country is justified in using a disproportionate amount of its skilled manpower in a given discipline on ERTS-related activities is a difficult decision in resource allocation.

5.2.3 Participating countries acquire data directly from ERTS and process and analyze it themselves

This form of participation would represent a significant step towards broadening the ERTS program to active international involvement in its operation. The United States would maintain responsibility for the fabrication and launch of ERTS, and would use United States data acquisition stations to obtain most of the output from the satellite. Certain other countries or regional groupings would also establish data acquisition stations capable of receiving the ERTS wide-band output. But, since the satellite would be 'turned on' by the ERTS Operational Control Center, when in the range of these stations, the United States would retain overall control of system operation. The data acquired by these other nations or regions would be processed and analyzed by them, without direct United States involvement, although duplicate data could be furnished.

The initial costs of a data acquisition station, data processing facility, and data analysis center is estimated at between \$5-\$10 million. It is expected that an investment of this size is likely to be undertaken only by developed countries, very large developing countries such as Brazil or India, or regional groupings of countries with a mutual interest in active participation in the ERTS program. Such an investment implies expectations of significant long-term benefits from an earth resources satellite survey program and a desire to be intimately involved in shaping the global scope and direction of that program.

Most advantages which can be claimed for this form of participation are predicated on the premise that some form of internationalization for the second generation developmental and the ultimate operational ERS systems is desirable and necessary. This form of participation provides an important step in this direction since it brings other countries or regions into the day-by-day activity of the ERTS program.

This form of participation would certainly remove most perceived fears of possible exploitation. For the participating country, this form of involvement would imply the development of significant capabilities in electronics, computer technology, data processing, and data analysis. These are some of the key technologies of the 'technotronic society.' The use of the ERTS program as an instrument for the acquisition of these capabilities is part of a broader process of global modernization. Countries which participate in this way will have a justified sense of involvement in this modernizing process. The enhancement of national morale resulting is a not-insignificant benefit.

Clearly the most important limitation is the expense and commitment involved. Given the experimental nature of the ERTS program, it is not yet clear whether the expected benefits from ERTS data can justify the investment of the funds needed to procure a data acquisition and processing capability. Certain countries—Canada, France, India, Australia (and other countries where United States data acquisition stations with antennas 40 ft or larger diameters are

located)—do already possess some of this capability, and for them the investment would not be as large. But for most developing countries, a \$10 million investment of scarce national resources at this stage in the development of the ERTS program may be difficult to justify. Further, given the early stages of the program, the design of the ground portion of the system may be so fluid that equipment needed to acquire and process the output of the sensors to be carried on the initial ERTS missions may not be useful for later ERS satellites.

5.3 Possible participation by the USSR

The history of attempts to implement a meaningful program of US/Soviet space cooperation is lengthy [3, 4]. Although the United States has over the years put forth a variety of suggestions, emanating from both public and private officials for cooperative space activity, the Soviet Government has almost always rejected or failed to respond to these overtures. The most significant exception to this generalization has been the agreement negotiated during 1962 between NASA's Dr Hugh Dryden and the Soviet Academy of Science's A. A. Blagonravov for cooperation in joint meteorological, geomagnetic, and passive communication projects. The subsequent execution of these agreements has been characterized by a low level of interaction between the United States and Soviet space programs. The Soviet Union has responded negatively or not at all to proposals for more dramatic and substantial cooperative programs. Most often, the rejections of United States overtures have been accompanied by statements indicating that a lessening of United States/Soviet political tensions should be a precondition for meaningful cooperation in technological matters.

During 1969, however, there have been apparent indications that cooperation in space activities is coming to be viewed by the Soviet Union as a means of lessening these tensions. In January 1969, for example, the President of the Soviet Academy of Sciences, Mstislav Keldysh, indicated that the USSR had no objections in principle to joint space flights with the United States. The Soviet Union has reported the Apollo manned flights completely and with praise for American achievements. Apollo 8 astronaut Frank Borman in June 1969 completed a nine-day tour of the Soviet Union during which many statements were made by Soviet officials of their desire to cooperate with the United States.

These indications of a climate favorable to US/Soviet space cooperation must be balanced against the past record discussed above. Whether the Soviet Union intends to reverse this policy is the critical element in any consideration of possible cooperative efforts in remote sensing projects between these two countries.

In examining the question of possible Soviet intervention and participation in ERTS, a number of assumptions are made. For example, it is assumed that the potential benefits of an ERS program are at least of as much interest to the USSR as to the United States. Several of the foreign policy goals ascribed to the United States above could also be suggested with respect to the Soviet Union. Further, the USSR is the only country other than the United States, which has developed the entire range of technological capabilities which has enabled it to

John Hanessian, Jr.

have undertaken a broadly-based program in such satellite application programs as communications and meteorology. Although these Soviet programs have not always been of the same scope as those performed by the United States, it is interesting to note that the Soviet Union has in almost every case paralleled the United States programs in space application.

Soviet representatives at the United Nations 1968 Outer Space Conference in Vienna stated that an ERS program is under development in the USSR. These representatives did not, at that time, indicate the details of this program but it was evident from their general attitude that the Soviet Union is definitely interested in satellite remote sensing activities. It may be inferred that as soon as they are ready with the program public mention of it will be made.

Assuming a modicum of coordination, a cooperative ERS program would present the opportunity for testing the flight performance of additional sensors and for exchanging applied research on signatures and ground truth. One possibility would be the orbiting of several satellites simultaneously which utilize different sensors but which would employ similar orbital parameters. This would enable the remote sensing of the same geographical area by different sensors. If one assumes a Soviet launched satellite in addition to one launched by the United States, it would also make possible considerably enhanced geographical coverage. Such a program might also result in lower cost to the United States since the Soviet Union in its program could cover some objectives, which if added to the United States program, would increase overall cost.

This concept of a coordinated program which does not require integration of hardware has a precedent in the portion of the Dryden-Blagonravov agreement relating to meteorological satellites. There was to be, according to the agreement, coordinated launching of such satellites, exchange of data from them on a real-time basis, and dissemination of the data to other nations [5]. The current plans for the World Weather Watch include these activities on the part of the United States and the Soviet Union. A recent report of the Space Science Board of the National Academy of Sciences suggests that cooperation between the United States and the USSR:

'May take the form of planning for, rather than the actual conduct of, space experiments. Joint planning would permit the maximum use of the special talents of each of the countries involved, while at the same time providing prestige returns to each. Cooperative planning has the additional attraction of not necessarily involving detailed hardware considerations; as a result, questions of security, in the narrow military sense, are not as relevant as they would be in joint implementation of space flights.' [6]

5.4 In conclusion

As has been described above several forms of international participation in an experimental earth resources survey satellite program are possible. Each has advantages and disadvantages for both the United States and the potential participating country. The technical constraints and realistic expectations need

International Aspects of Earth Resources Survey Satellite Programs

to be carefully considered in any feasibility evaluation that may be carried out by a prospective participant. For developing countries technical assistance, both in the planning and operational stages will be necessary. Such assistance can be provided by such industrialized countries as the United States, or through regional or international multilateral agencies. It is also quite possible that private industry could play a leading role in such efforts. The potential participation of the USSR in such a program must be viewed not only with the optimism engendered by recent statements, but also by reflection on the experience, of a decade of space history. Finally, the earth resources survey satellite concept is one which, if exploited in an optimum manner, could provide an ideal opportunity for the technologically advanced nations of the world to converge their interests with the aspirations of the many developing countries in their effort to build a just, peaceful, and economically progressive world community.

REFERENCES

- [1] Airphoto Use in Resource Management, US Department of Agriculture, GPO, May 1969, p. 3.
- [2] F. J. OSSENBECK and P. C. KROECK (eds), Open Space and Peace, Stanford, 1964.
- [3] ARNOLD FRUTKIN, International Cooperation in Space, Prentice-Hall, 1965, Chapter 3.
- [4] DON KASH, The Politics of Space Cooperation, Purdue Press, 1967, Chapter 6.
- [5] See Reference [3], p. 96.
- [6] Planetary Exploration, 1968-1975, Report of a study by the Space Science Board, National Academy of Sciences, July 1968, p. 17.

BIBLIOGRAPHY

- GENE BYLINSKY, From a High-Flying Technology, A Fresh View of Earth, Fortune, 1 June 1968, pp. 100-103, 144, 146, 148.
- ROBERT N. COLWELL, Remote Sensing of Natural Resources, Scientific American, January 1968, pp. 54-69.
- Cornell University, Center for Aerial Photographic Studies, Potential Benefits to be Derived from Applications of Remote Sensing of Agricultural, Forest, and Range Resources, Cornell, 1967.
- WILLIAM A. FISCHER, Potential Uses of Space Data in Survey of Soil, Water, and Suburbia, Paper presented at Louisiana Conference on Soil, Water and Suburbia. February 1968.
- IRWIN HERSEY, Satellites for Small Nations, Science and Technology, December 1968, pp. 54, 56, 58.
- International Astronautical Federation, 19th Congress, New York, New York, October 1968. Papers presented at this Congress relevant to this paper include Colwall (AS.163), Fischer, (AS.155), Miles (E.182), Miller and Gurk (TS.186) and Morton (TS.190).
- RICHARD S. KAHN, Expanded Role in Space Sought for UN, Aviation Week and Space Technology, 26 May 1969, pp. 57-60.
- AMROM H. KATZ, Reflections on Satellites for Earth Resource Surveys: Personal Contributions to a Summer Study, RAND Paper P-3753, 1967.

John Hanessian, Jr.

- University of Michigan, Institute of Science and Technology, Peaceful Uses of Earth-Observation Spacecraft, 3 volumes, NASA Contractor Reports (no dates).
- University of Michigan, Institute of Science and Technology, Proceedings of the Fifth Symposium on Remote Sensing of Environment, 16-18 April 1968, Willow Run Laboratories, 1968.
- University of Michigan, Infrared and Optical Sensor Laboratory, Peaceful Uses of Earth-Observation Spacecraft, Volume III: Sensor Requirements, NASA Contractor Report CR-588, September 1966.
- G. K. C. PARDOE, Application Satellites Other Than Communications, *Spaceflight* 10, 434 (1968).
- D. C. PARKER, and M. F. WOLFF, Remote Sensing, *International Science and Technology*, July 1965, pp. 20-31, 73.
- Planning Research Corporation, A Study of the Economic Benefits and Implications of Space Station Operations, Los Angeles, 1968.
- Purdue University, Agricultural Experiment Station, Laboratory for Agricultural Remote Sensing, Remote Multispectral Sensing in Agriculture, Annual Report, Volume 2, Purdue University Research Bulletin No. 932, July 1967, Lafayette, Indiana.
- Remote Multispectral Sensing in Agriculture, Annual Report, Volume 3, Purdue University Research Bulletin No. 844, September 1968, Lafayette, Indiana.
- Radio Corporation of America, Defense Electronic Products, Astro Electronics Division, Cost Benefit Study of the Earth Resources Observation Satellite System: Grazing Land Management, Princeton, New Jersey, 1968.
- EDWARD RISLEY, Remote Sensors for Regional Study: Some Policy Considerations, Paper presented at Annual Meeting of the American Association for the Advancement of Science, New York, December 1967.
- Stanford University, School of Engineering, Demeter: An Earth Resources Observation System, Stanford, California, 1968.
- PAUL G. THOMAS, Earth-Resource Survey from Space, *Space/Aeronautics*, July 1968, pp. 46-53.
- United Nations, Committee on the Peaceful Uses of Outer Space. Report to 23rd Session on the General Assembly. (UN Document A/7285, 1968.)
- Office of Public Information, Space Science and Technology: Benefit to Developing Countries: the United Nations Conference on the Exploration and Peaceful Uses of Outer Space, Vienna, 14-27 August 1968. United Nations, 1968.
- Conference on the Exploration and Peaceful Uses of Outer Space, Vienna, Austria, 14-27 August 1968. Papers presented at the Conference relevant to this paper include Jaffe (Int.5), Park (IV.1), Robinore (IV.2), Siebert (IV.3), Pecora (IV.4), Sherman and Chaney (IV.5), de Mendonca (IV.7), Fortier (IV.9), Jaffe (VIII.2), Frutkin (VIII.3), Pollack (VIII.5), Loy (VIII.6), ESRO (VIII.11), Sierra Leone (VIII.14), Rose and Rettie (VIII.15), Parin and Gazenko (VIII.19), Petrov (VIII.20), UN Secretary General (VIII.25), UN Secretary-General (VIII.27), Lewis (IX.2), and Castruccio (Background Paper Number 13).
- US Congress, House of Representatives, Committee on Science and Astronautics, Subcommittee on NASA Oversight, The National Space Program—Its Values and Benefits, 90th Congress, 1st Session, 1967: Earth Resources Program, pp. 32-38.
- US Congress, House of Representatives, Committee on Science and Astronautics, Subcommittee on NASA Oversight, Earth Resources Satellite System, 90th Congress, 2nd Session, 1968.
- US Congress, Senate, Committee on Aeronautical and Space Sciences, NASA Authorization for Fiscal Year 1968, 90th Congress, 1st Session, 1967, pp. 60-61, 168-169, 341-343, 361-364, 405-414.
- Committee on Aeronautical and Space Sciences, NASA Authorization for Fiscal Year 1969, 90th Congress, 2nd Session, 1968, pp. 287-288, 297-299, 308-311, 667-693.

International Aspects of Earth Resources Survey Satellite Programs

- US Department of Agriculture, Earth Resource Satellites, Statement by Dr A. B. Park before the subcommittee on Space Science and Applications, Committee on Science and Astronautics, House of Representatives, 19 March 1969.
- Economic Research Service, Agricultural Applications of Remote Sensing—The Potential from Space Platforms, Agricultural Information Bulletin Number 328, Government Printing Office, 1967.
- US Department of the Interior, Office of the Secretary, Earth Resource Observation Satellite Program—Status and Plans, 1967, Washington, DC (mimeograph).
- Statement of W. T. Pecora Director, US Geological Survey, Statement on Earth Resource Survey Satellites before the Subcommittee on Space Sciences and Applications, Committee on Science and Astronautics, House of Representatives, 19 March 1969.
- US NASA, A Survey of Space Applications, NASA SP-142, Washington, DC, April 1967.
- Objectives and Goals in Space Science and Applications, NASA SP-162, Washington, DC, 1968.
- Goddard Space Flight Center, Design Study Specifications for the Earth Resources Technology Satellite ERTS-A and B, NASA, Greenbelt, Maryland, 1969.
- Goddard Space Flight Center, Earth Resources Technology Satellite Study, NASA, Greenbelt, Maryland, 1967.
- Space Applications Programs: Earth Resources Survey Program, Statement of Leonard Jaffe, Director of Space Applications Programs before the Subcommittee on Space Science and Applications, Committee on Science and Astronautics, House of Representatives, Washington, DC, March 19, 1969.
- Westinghouse Electric Corporation, Defense and Space Center, EROS Application Benefit Analysis, Final Report. Baltimore, Maryland, 1967.
- F. J. WOBBER, Environmental Studies Using Earth Orbital Photography, *Photogrammetria* 24, 107 (1969).

(Presented at the International Summer School of the British Interplanetary Society on 'Earth Observation Satellites' held at Cambridge, 14-25 July 1969—a NATO Advanced Study Institute)